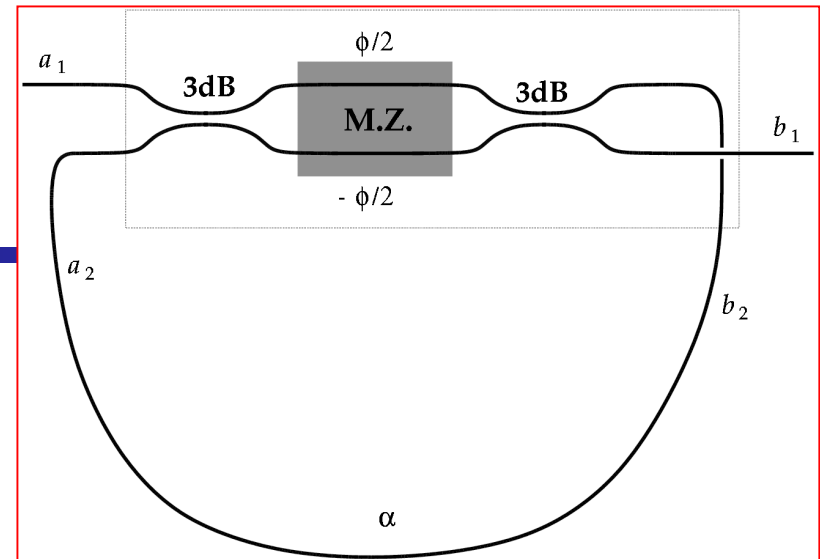


# Controlled Waveguide-Resonator Coupling

*California Institute of Technology*

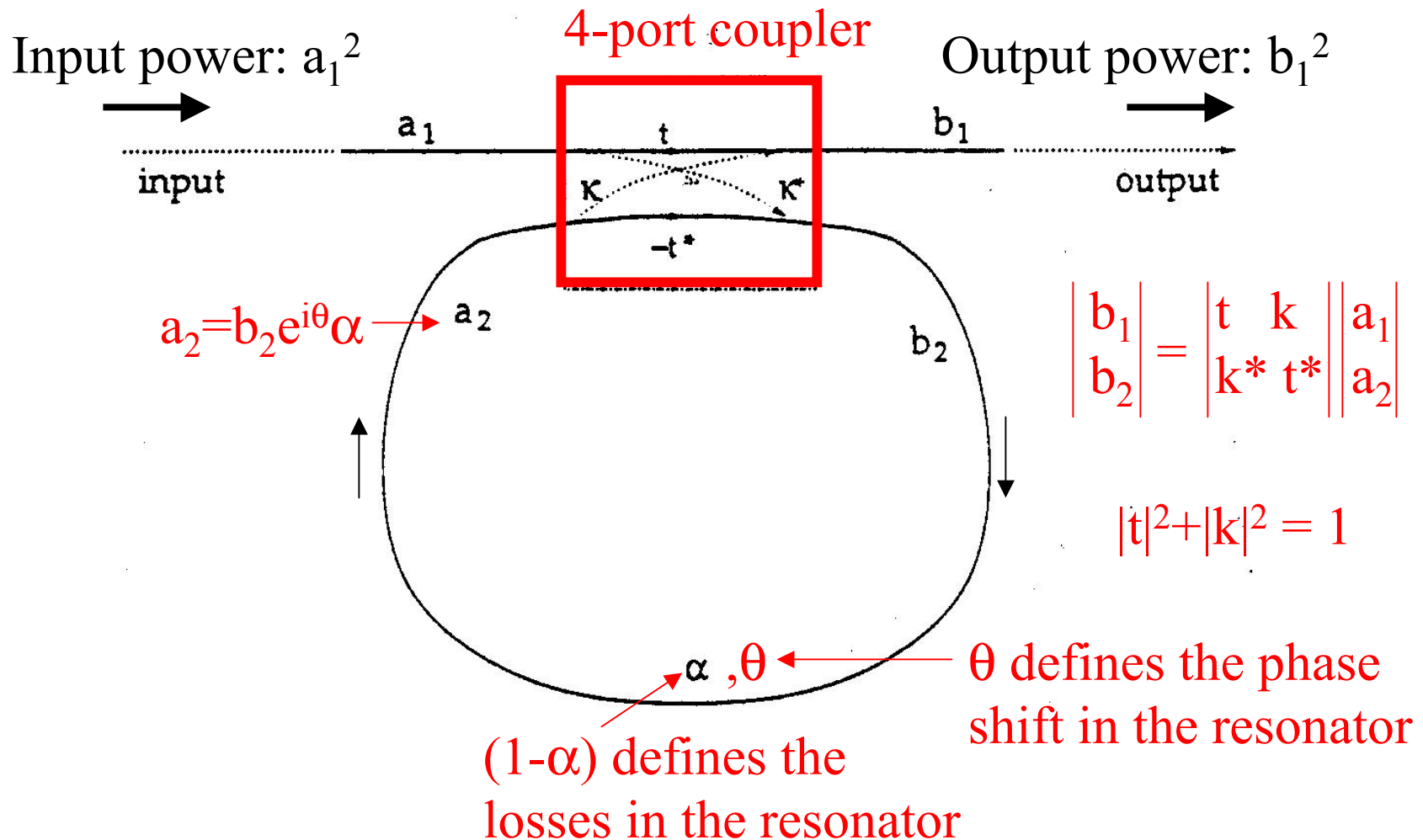
- Amnon Yariv
- Axel Scherer

# Program Objectives



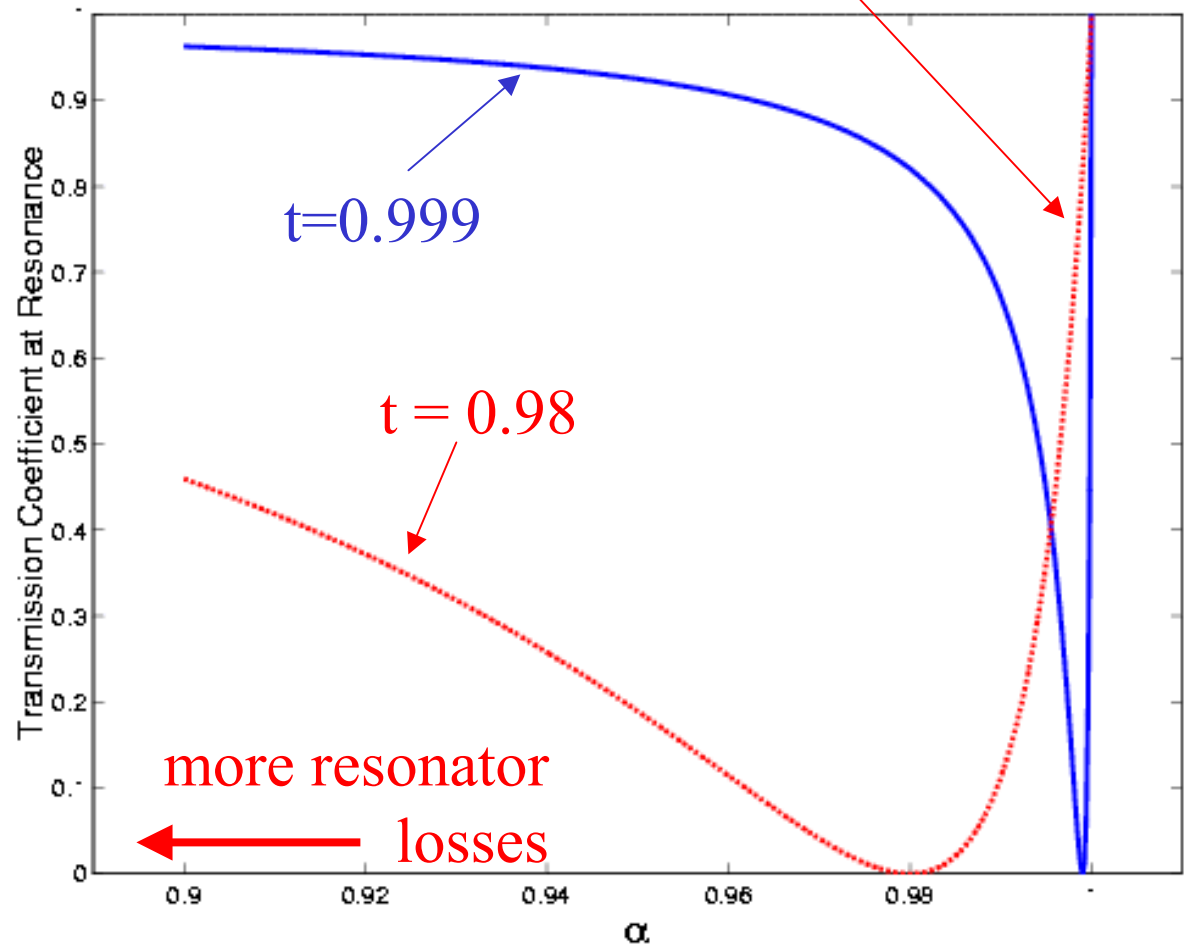
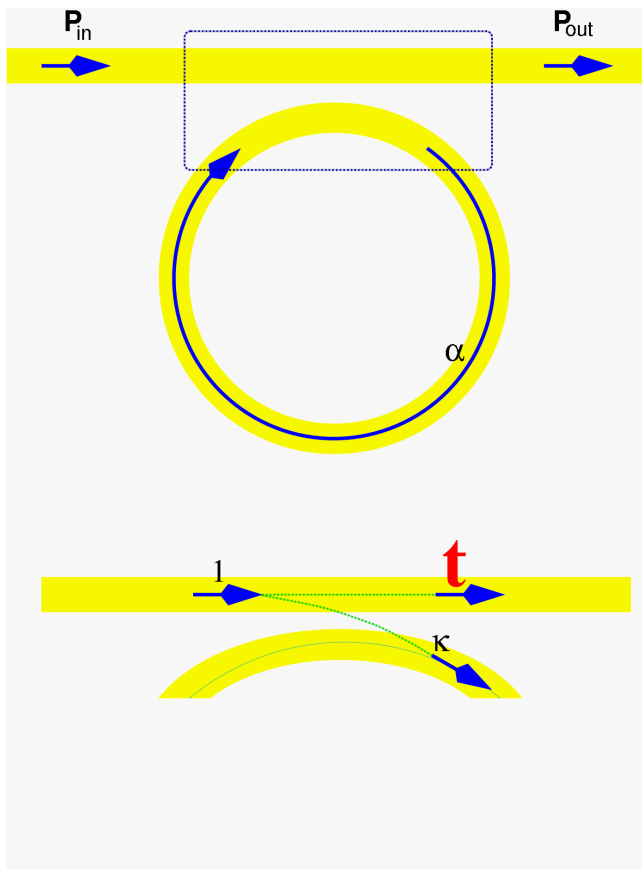
- Develop technology for fabricating optical resonators coupled to dielectric waveguides
- Control the coupling by incorporating electro-optically controlled Mach-Zehnder interferometers into the resonators
- Control the gain and coupling independently
- Demonstrate routing, switching and modulation of optical beams using this new geometry

# Simple Schematic Illustrating Critical Coupling Terminology



# Coupling to a resonator supporting a traveling wave mode

We hope to take advantage of the steep slope of the Transmission versus loss ( $\alpha$ ) curve.



# Demonstration of Critical Coupling in $\text{SiO}_2$ Microspheres

260 OPTICS LETTERS / Vol. 25, No. 4 / February 15, 2000

## Highly efficient optical power transfer to whispering-gallery modes by use of a symmetrical dual-coupling configuration

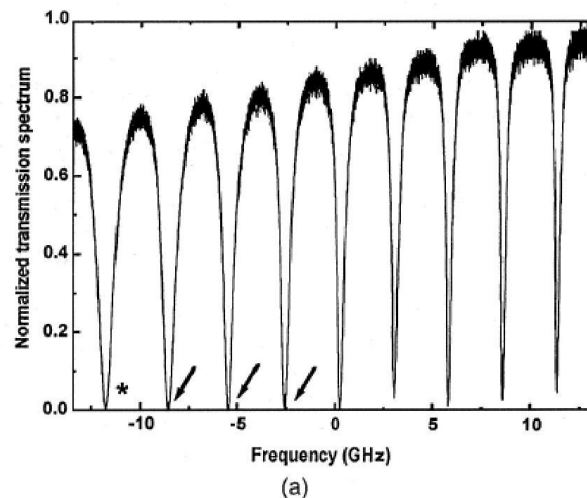
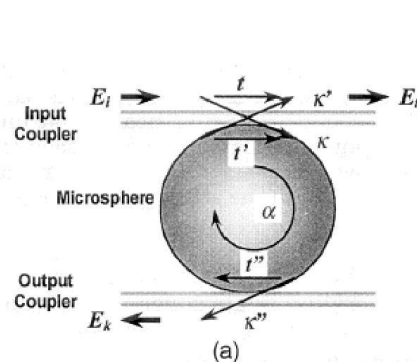
Ming Cai and Kerry Vahala

*Department of Applied Physics, California Institute of Technology, Pasadena, California 91125*

Received September 28, 1999

We report that greater than 99.8% optical power transfer to whispering-gallery modes was achieved in fused-silica microspheres by use of a dual-tapered-fiber coupling method. The intrinsic cavity loss and the taper-to-sphere coupling coefficient are inferred from the experimental data. It is shown that the low intrinsic cavity loss and the symmetrical dual-coupling structure are crucial for obtaining the high coupling efficiency. © 2000 Optical Society of America

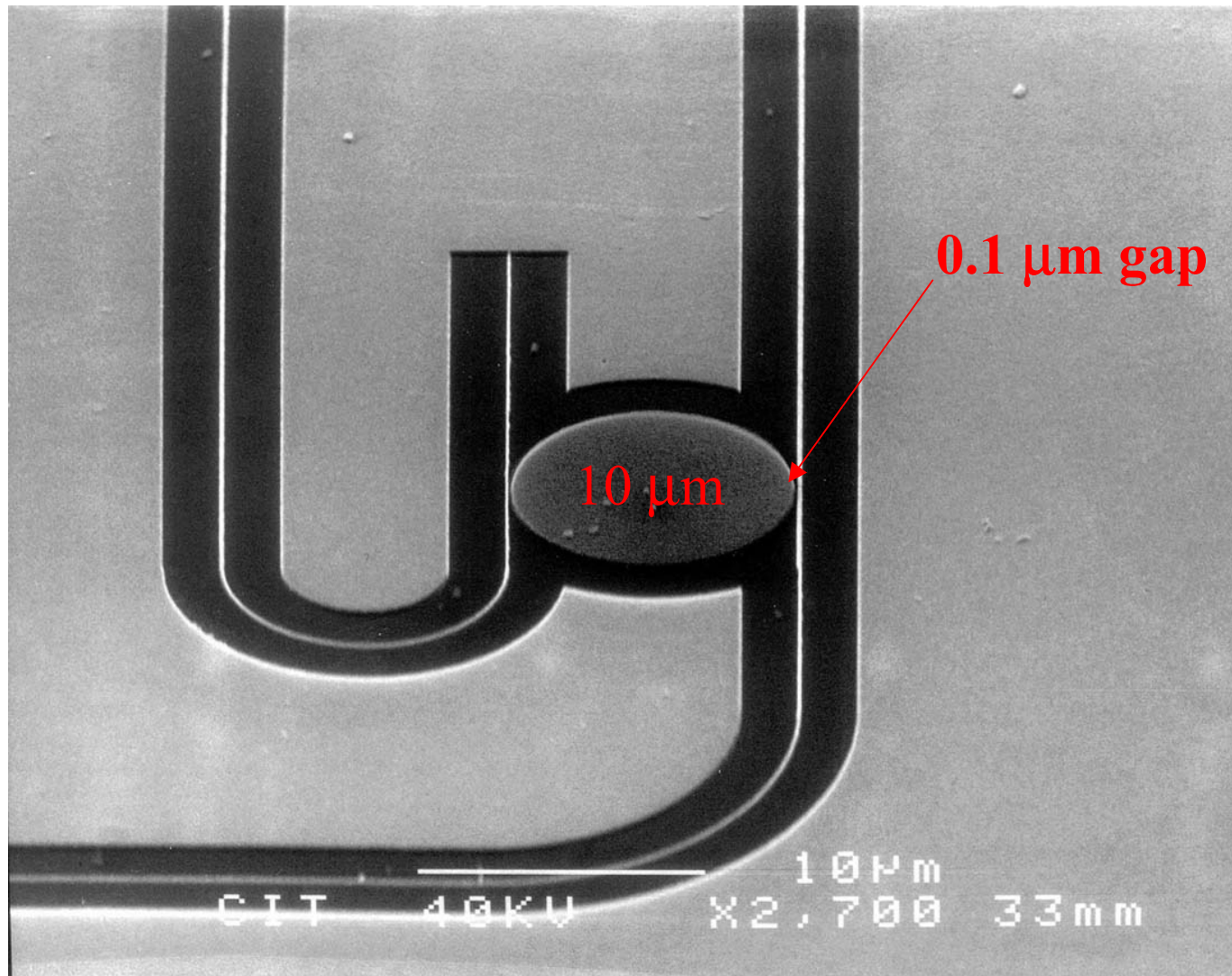
OCIS codes: 230.5750, 230.3990, 060.1810, 230.1150.



Previous work with  $>100$  micron Silica resonators clearly demonstrates the potential for using resonant coupling in add/drop filters

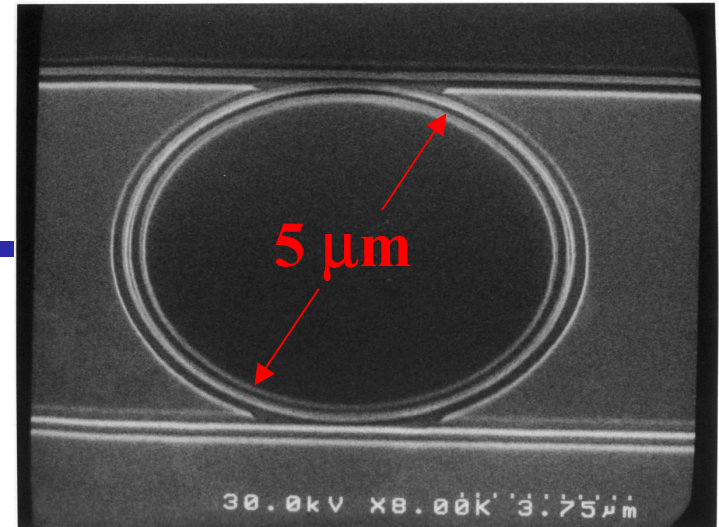
(Work by Vahala's group)

# Microfabricated Disk Resonator



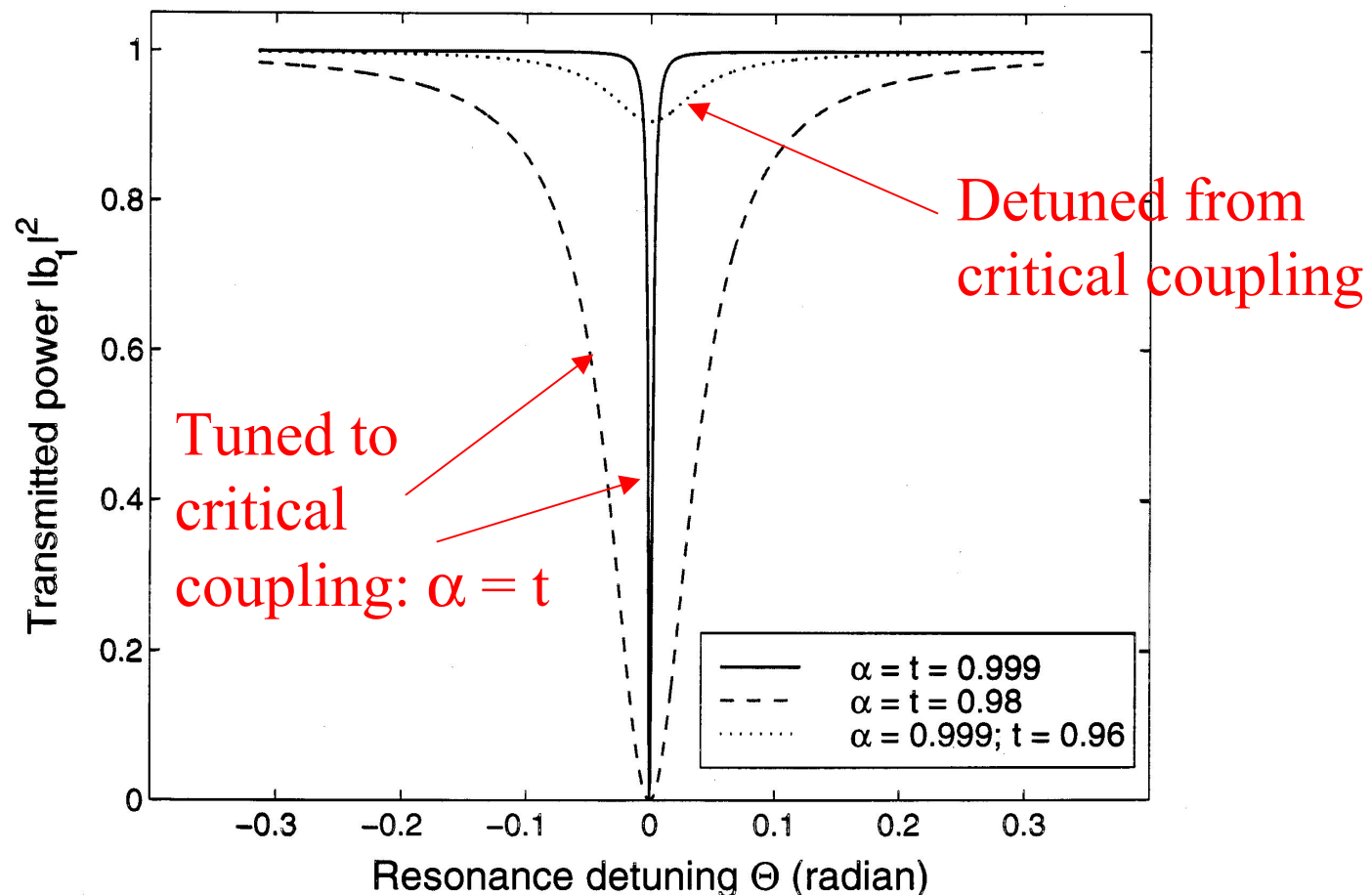
# Technical Accomplishments

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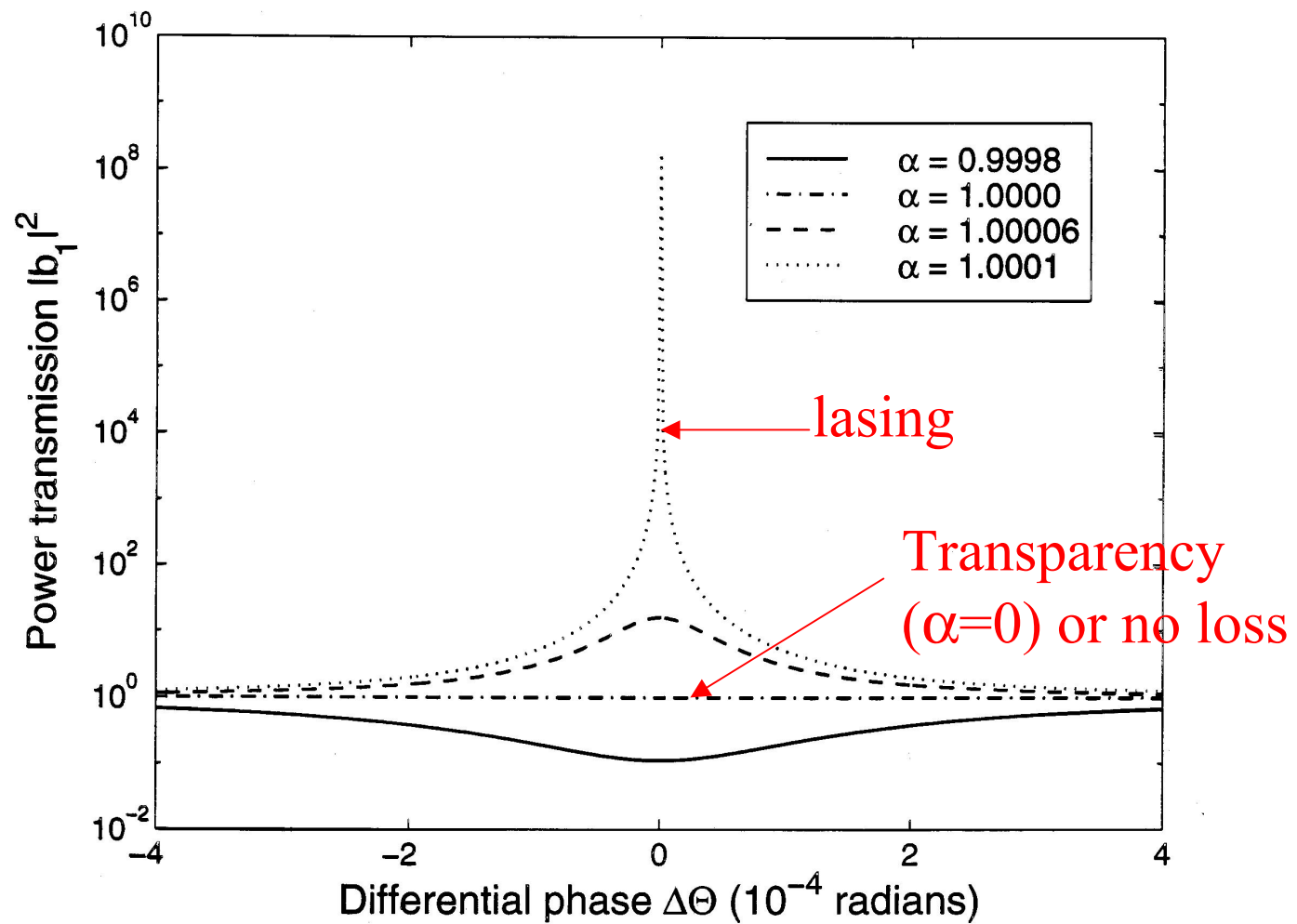


- Design of optical resonator based modulators/switches
- Fabrication of resonator structures in thin monocrystalline silicon waveguides
- Optimization of lithography and etching conditions for small gaps between waveguides and resonators
- Modeling of expected optical response from waveguide/resonator structures with tuneable losses and gain

# Effect of resonator loss on the peak shape when tuned and detuned from critical coupling

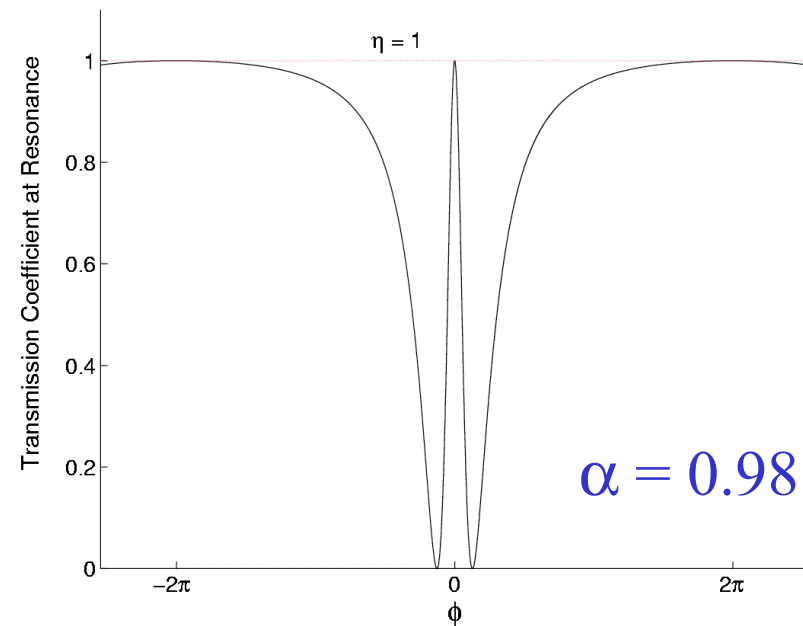
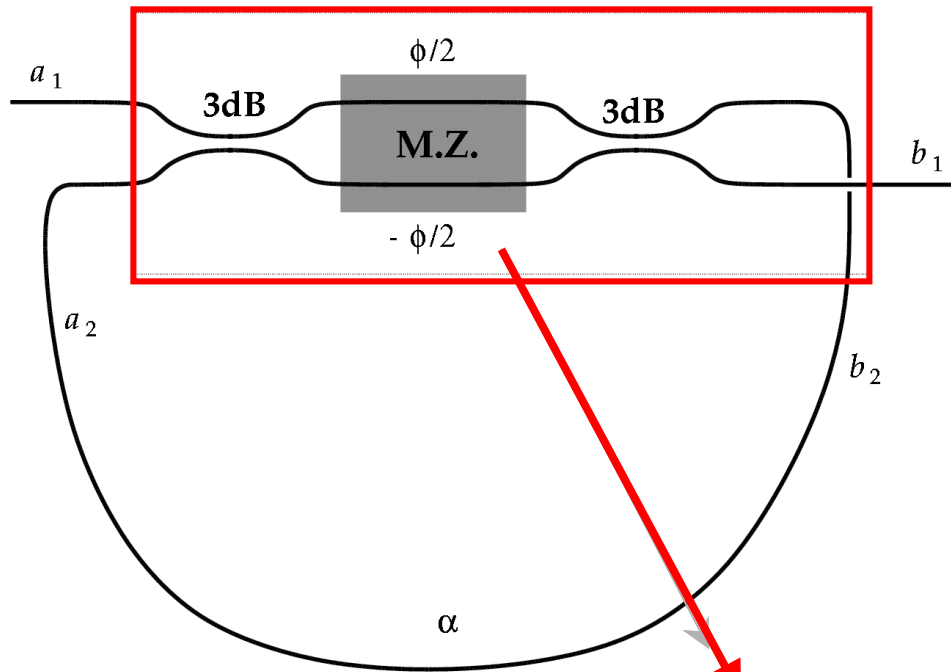


# Effect of gain on Resonance



# Waveguide-resonator controlled coupling

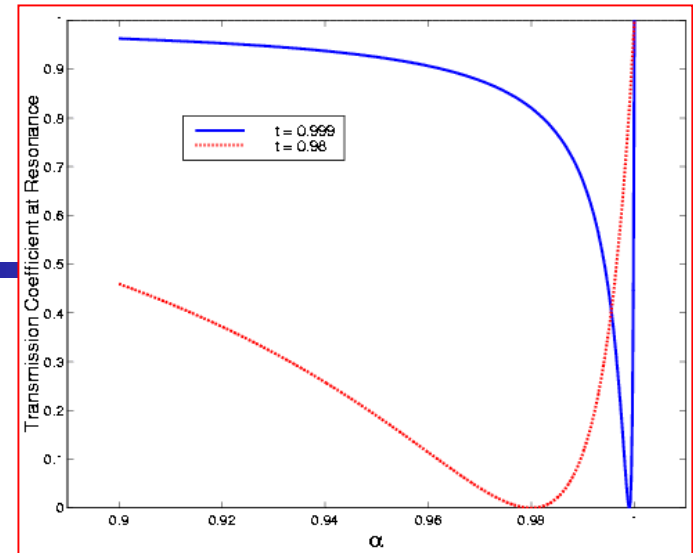
A Mach-Zehnder variable coupler can be used to control the resonator coupling and the transmission coefficient



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = i \begin{bmatrix} \cos \frac{\phi}{2} & -\sin \frac{\phi}{2} \\ \sin \frac{\phi}{2} & \cos \frac{\phi}{2} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

Phase controlled  
by Mach-Zehnder  
applied voltage

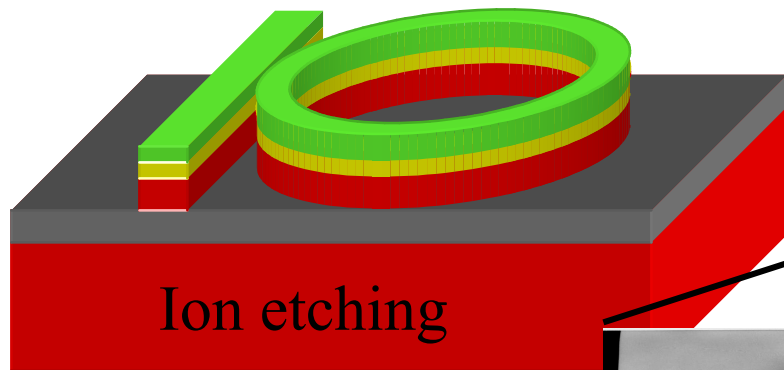
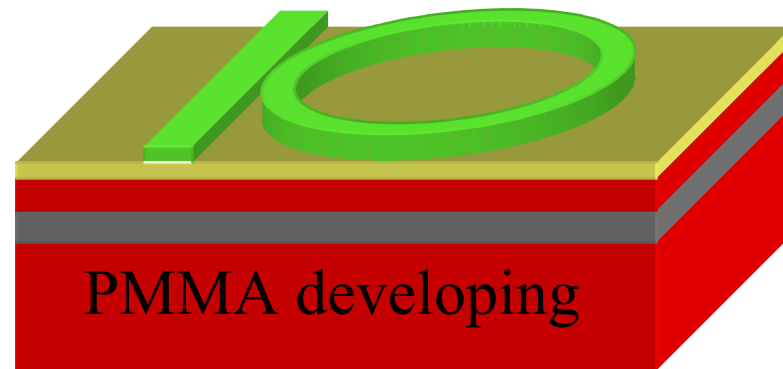
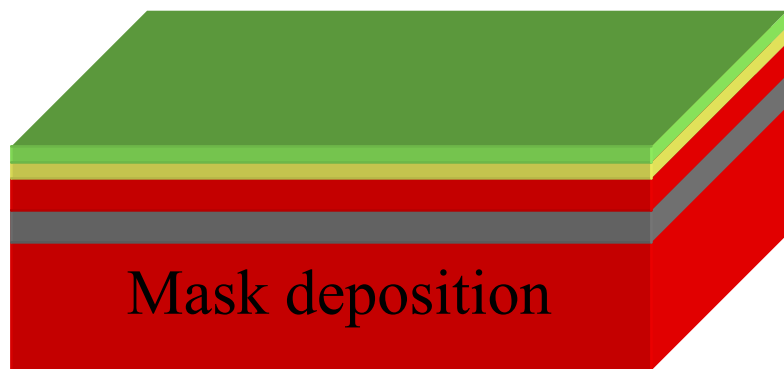
# Key Milestones for 2001



- Construct small (3-10 micron diameter) disk, ring and racetrack resonators coupled to optical waveguides in silicon and InGaAsP
- Demonstrate larger ring resonators in polymer waveguides
- Measure Qs of these resonators and show critical coupling
- Incorporate gain into the resonators and measure output light
- Develop more efficient couplers to mode-match small single mode waveguides with optical fibers

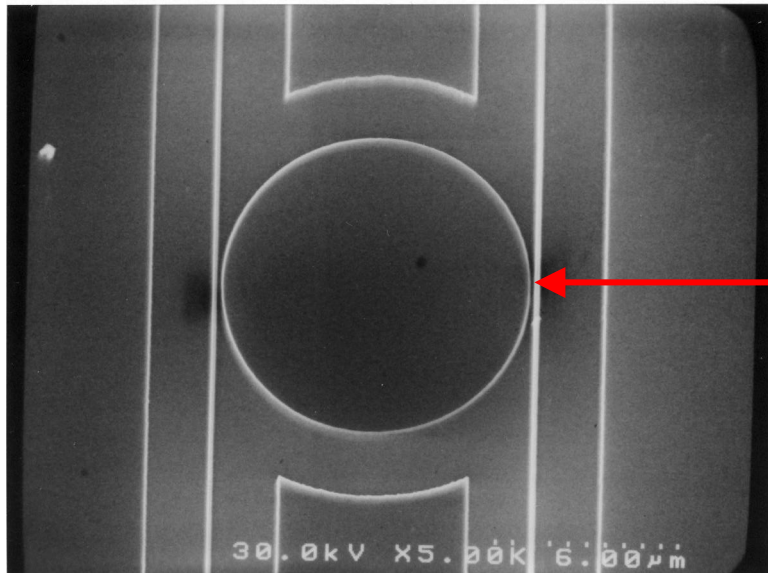
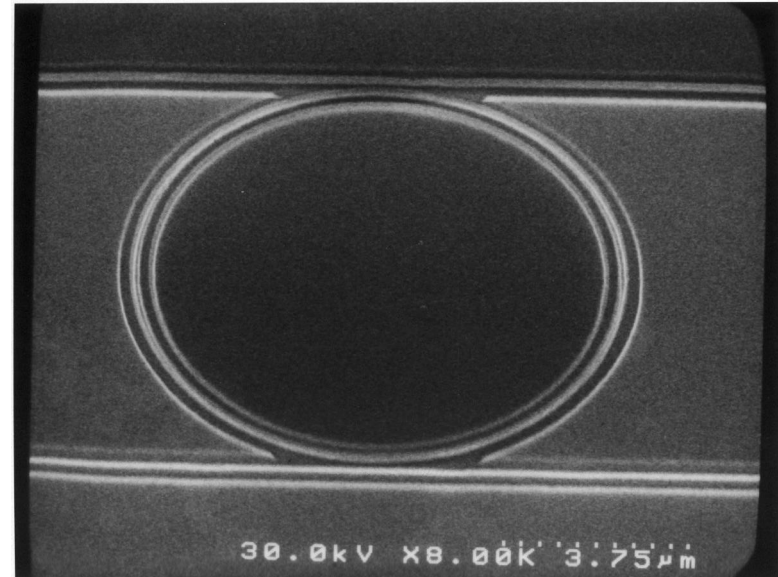
# Process Sequence for Defining Resonators

Disc and ring resonators are constructed by lithography, ion etching, and chemical etching



# Etched Ring Resonators in Single Crystal Si on SiO<sub>2</sub> (SOI) Wafers

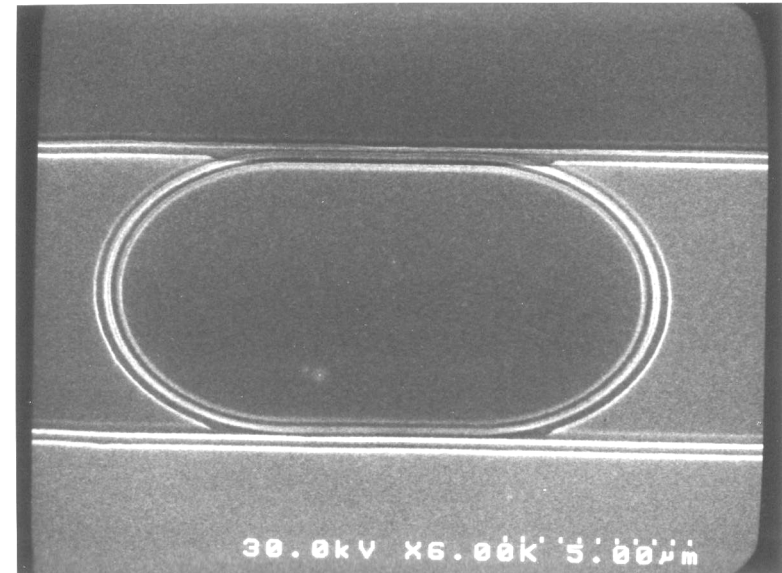
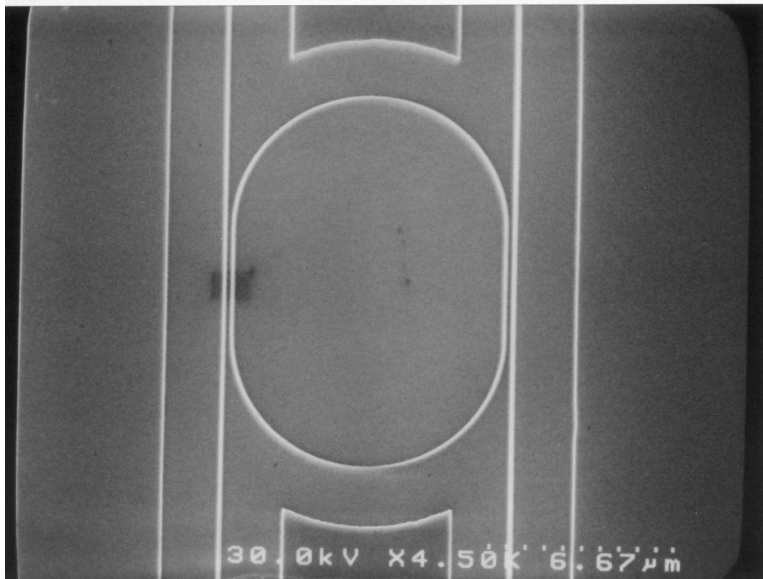
Silicon on Insulator  
Waveguides were fabricated  
and connected to ring and  
disc resonator structures.



Gap spacings between the  
resonator and the waveguides  
were lithographically  
controlled down to 70 nm

# “Racetrack” resonators

Coupling can be controlled by extending the coupling length and using a “racetrack” design.



Lithography and anisotropic etching can be used to define the waveguides, and nonlinear polymers can be used to tune the coupling

# New Generation of Optical Routers

Laser beams can be switched on and off or routed selectively by electrically controlled coupling to microresonators.

Fig. 5.

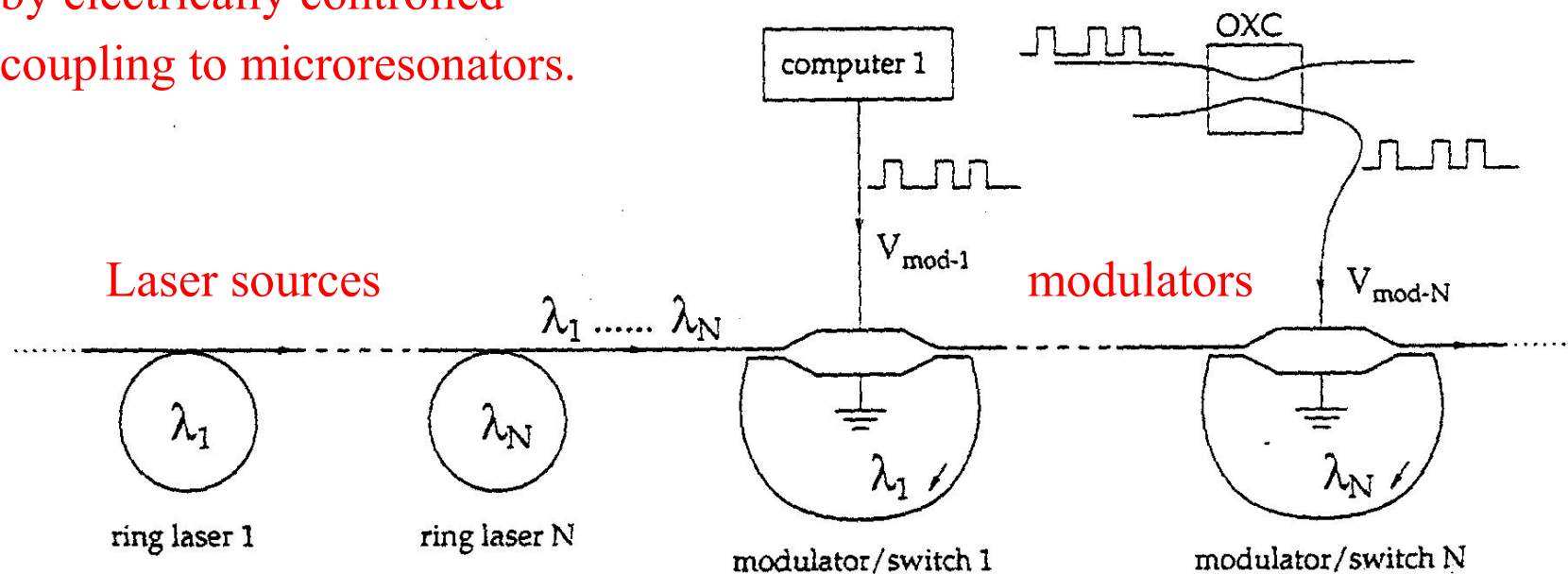


Fig. 6. Optical fiber lasers  $\lambda_1, \dots, \lambda_N$  are in turn controlled or modulated by data streams.

# Technology

## Transition/Insertion/Commercialization

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- The fabrication and design details of the proposed devices will be shared with several start-up companies as well as more established industrial partners, such as Ortel corporation.